



Solar Tracking with Photovoltaic Panel

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Abstract

Algeria encourages the development of renewable energies and in particular photovoltaic solar energy and this with an aim of answering at the request of electricity of the most stripped places and where the advance of electricity is difficult. Many scientists and researchers do not cease developing various methods of calculating for collect the maximum solar radiation and to optimize the electric power extracted of the photovoltaic generators.

We develop in our study the effect of the slope and the orientation on the maximum power extracted from a photovoltaic module. We present the simulation of the sun trajectory tracking with a PV panel, keeping continuously the panel surface oriented face the sun.

Three positions of the PV panel are considered, normal (full tracking), tilted fixed and horizontal. The aim of this study is to maintain the panel perpendicular to the solar rays, therefore to define the solar angles azimuth (α), altitude (h) and the inclination β of the PV panel at each hour of the day. For that we carried the programme of the sun trajectory tracking along the day using the Matlab software.

We compare the curves obtained, of solar flux, the characteristics current-tension $I(V)$ and the characteristics power-tension $P(V)$ for the studied cases. Our results are in good agreement with those experimental.

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Keywords: Photovoltaic (PV), solar azimuth angle, solar altitude angle, solar flux.

1. Introduction

Algeria is a very sunny country, the sun is shining 3,500 hours. The potential is equivalent to eight times the gas recourses. The extraction of electric power from solar energy makes it possible to save gas for other applications and to reduce approximately 33,000 tons of emitted CO₂.

The sun emits 175 billion KW per hour, and provides a significant energetic potential. For the production of the solar electricity whose request and consumption do not cease growing around the world.

In this study we choose the year's days where the orbit of the earth passes by the four seasons when the solar declination δ varies. These days are: 21st March, 21st June, 21st September and 21st December. The solar declination δ is calculated by the equation (1).

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The PV module under consideration for simulation is the PWX 500 polycrystalline marketed by international PHOTOWAT subsidiary of Matrix Solar Technology, whose parameters given are as follows: at standard test conditions $V_{co}=21.6$ V, $I_{cc}=3.05$ A, $I_{max}=2.80$ A and $V_{max}=17$ V.

2. System description

The general diagram (figure 1) of the system include a computer (PC-1) to carry out the calculation program of the actuators (Ac-2) which is composed by two engines (step by step) and the photovoltaic panel (PV-3).

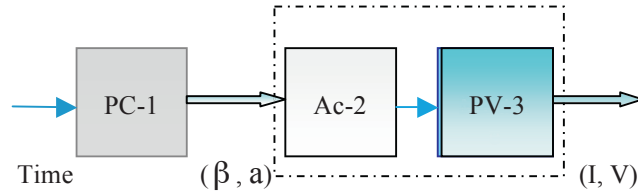


Fig. 1: Elementary diagram of the control device of a PV panel

The orientation and the slope of the panel depend directly on the solar angles (altitude (h) and azimuth (a)) as represented in figure 2.

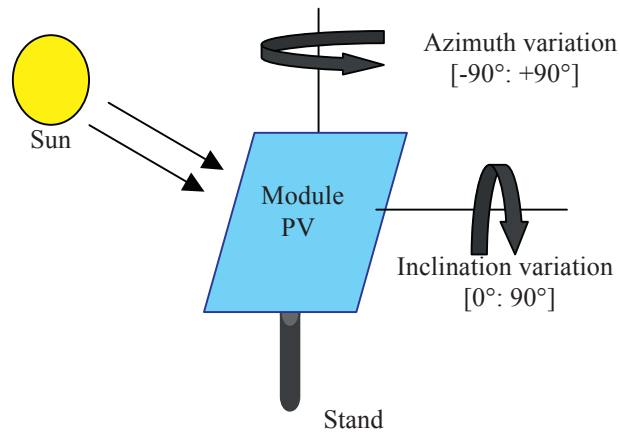


Fig. 2: Orientation of PV panel following two axes the azimuth and the inclination

3. Simulation of system

All The solar declination δ , the hour angle ω and the true solar time TS are calculated by:

$$\delta = 23.45^\circ \sin[0.980^\circ(N + 284)] \quad (1)$$

$$\omega = 15^\circ(TS - 12) \quad (2)$$

$$TS = TL \pm C + ET + \frac{(l_{SL} - l)}{15} \quad (3)$$

Where N is the number of the day chosen during the year, TL local standard time, C is the difference between the standard time and the hour of the universal time zone, ET is the equation of time, l_{SL} is standard longitude and l is local longitude.

The general equation used for the calculation of the angles (a , h) for various positions of the panel is: (a , h) for various positions of the panel is:

$$\begin{aligned} \cos(\theta) = & \sin(L) \sin(\delta) \cos(\beta) - \cos(L) \sin(\delta) \sin(\beta) \cos(a) \\ & + \cos(L) \cos(\delta) \cos(\omega) \cos(\beta) + \sin(L) \cos(\delta) \sin(\beta) \cos(a) \\ & + \cos(\delta) \sin(\omega) \sin(\beta) \sin(a) \end{aligned} \quad (4)$$

With θ is the solar incidence angle (the angle between the sun's rays and the normal on a surface) and L is the local latitude.

3.1 Perpendicular surface

For the surface continuously oriented face the sun has an angle of incidence $\theta = 0^\circ$ so $\cos(\theta) = 1$ and the equation (4) becomes :

$$\begin{aligned} 1 = & -\cos(L) \sin(\delta) \cos(a) + \sin(L) \cos(\delta) \cos(\omega) \cos(a) \\ & + \cos(\delta) \sin(\omega) \sin(a) \end{aligned} \quad (5)$$

The mathematical expression for the solar azimuth angle is

$$\sin(a) = \frac{\cos(\delta) \sin(\omega)}{\cos(h)} \quad (6)$$

Where the angle H is calculated by:

$$h = \arccos\left(\frac{\cos(\delta) \sin(\omega)}{\sin(a)}\right) \quad (7)$$

And:

$$\beta = 90 - h \text{ (}^\circ\text{)} \quad (8)$$

The direct solar radiation can be estimated by:

$$S = F * C_I \quad (9)$$

Where F is incidental flux:

$$F = E_{sol} \exp(-T_L / (0.9 + \sin(h))) \text{ [} W / m^2 \text{]} \quad (10)$$

With $E_{sol} = 1370 \text{ (} W/m^2 \text{)}$ and T_L is the turbid factor of Linke .

C_I is the coefficient of orientation defined by :

$$C_I = \sin(\beta) \cos(h) \cos(o - \beta) + \cos(\beta) \sin(h) \quad (11)$$

The diffuse solar radiation is evaluated by the following expression

$$D = 125 * \sin(h)^{0.4} * ((1 + \cos(\beta)) / 2) + 211.86 \sin(h)^{1.22} * ((1 - \cos(\beta)) / 2) \quad [W / m^2] \quad (12)$$

The total radiation is the sum of the diffuse and the direct radiations;

$$G = S + D \quad [W/m^2] \quad (13)$$

3.2 Fixed tilted surface

The fixed tilted panel is a particular case of the mobile perpendicular panel. We fix the slope and the orientation in the equations (11) and (12).

3.3 Horizontal surface

For the horizontal surface the equation (4) becomes:

$$\sin(h) = \sin(L) \sin(\delta) + \cos(L) \cos(\delta) \cos(\omega) \quad (14)$$

The direct solar radiation can be calculated by:

$$S = F * \sin(h) \quad (15)$$

The diffuse solar radiation on a horizontal surface can be determined by:

$$D = 54.8 \sqrt{\sin(h)} * [T_L - 0.5 - \sqrt{\sin(h)}] \quad (16)$$

For the three studied cases the current and the tension are evaluated by:

$$I_{cc2}(G_2, T_2) = I_{cc1}(G_1, T_1) \frac{G_2}{G_1} + \alpha(T_2 - T_1) \quad (17)$$

$$V_{co2}(G_2, T_2) = V_{co1}(G_1, T_1) + A \ln\left(\frac{G_2}{G_1}\right) + \beta(T_2 - T_1) \quad (18)$$

The power is the product of the current and the tension being able to be extracted from the module photovoltaic;

$$P = I * V \quad (19)$$

4. Results and Discussion

4.1 Case 1: March 21

The solar rays arrive with an altitude angle of 53° at 13h, the corresponding slope of the panel is of 37° and the azimuth is of -3° (Fig.3).

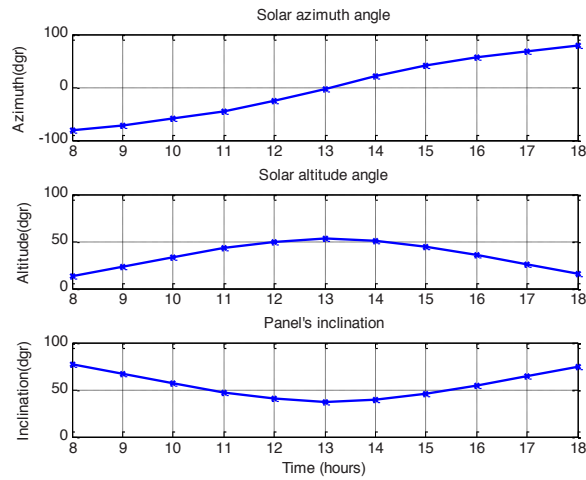


Fig.3: Variation of azimuth (a), altitude (h) and inclination (β) the 21st March

The radiation curves of March 21 show that the total solar flux is about 960 (W/m^2) on a perpendicular surface. It is about 878 (W/m^2) on a fixed tilted plan and it reaches 768 (W/m^2) on a horizontal surface (Fig.4).

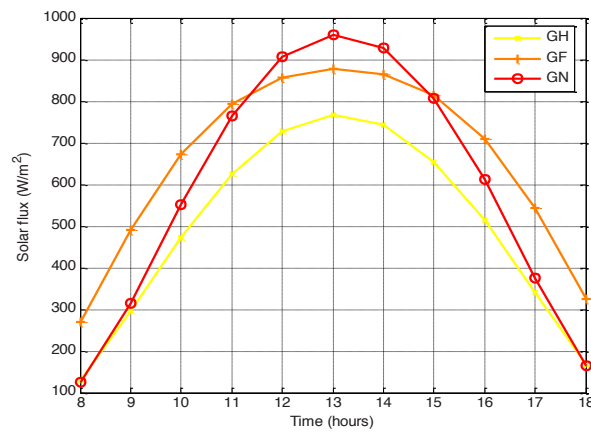


Fig.4: Variation of solar flux for perpendicular plan (GN), fixed plan (GF) and horizontal plan (GH) the 21st March

The figure 5 shows the direct influence of the solar radiation on the characteristics current-tension $I(V)$ of PV module .

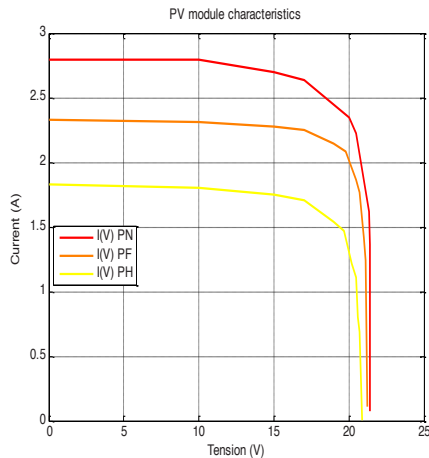


Fig.5: Variation of the characteristics $I(V)$ of PV module on March 21 for the three positions perpendicular (PN), fixed (PF) and horizontal (PH)

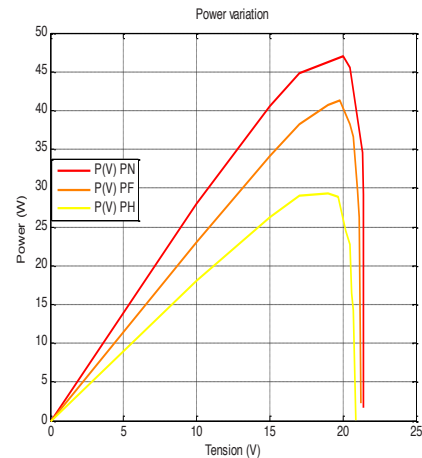


Fig.6: Variation of the characteristics $P(V)$ of PV module on March 21 for the three positions perpendicular (PN), fixed (PF) and horizontal (PH)

We note in the figure 6 that the power is maximum for the position of the perpendicular panel

4.2 Case 2: June 21

In the figure 7 we see that the solar altitude angle is maximum at 13h reaching 72° , the slope of the panel must be of 18° .

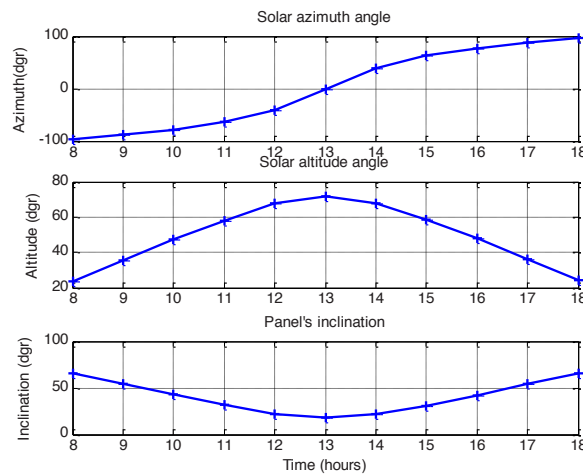


Fig.7: Variation of azimuth (a), altitude (h) and inclination (β) on June 21

The figure 8 shows that the solar flux reaches $1,044 \text{ (W/m}^2\text{)}$ in June on a perpendicular surface.

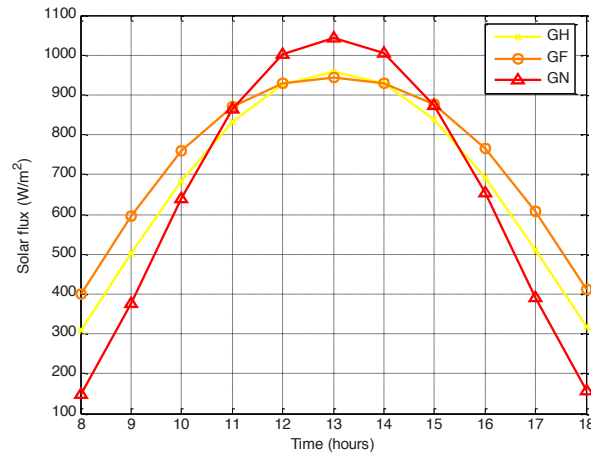


Fig.8: Variation of solar flux for perpendicular plan (GN), fixed plan (GF) and horizontal plan (GH) on June 21

The figures (9 and 10) show that the characteristics $I(V)$ and $P(V)$ of the module are almost identical for the fixed plan and horizontal plan. The solar flux varies only slightly with position. But for perpendicular plan the extracted power is higher than the extracted power for the horizontal plan and the fixed plan.

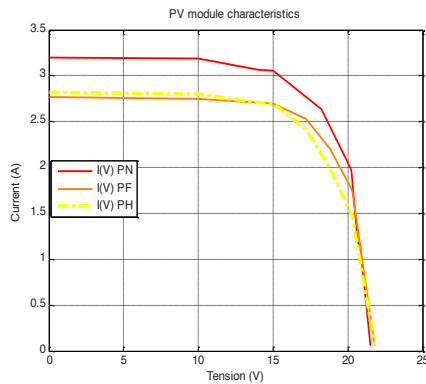


Fig.9: Variation of the characteristics $I(V)$ of PV module on June 21 for the three positions normal (PN), fixed (PF) and horizontal (PH)

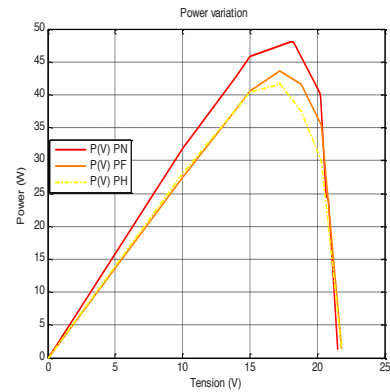


Fig.10: Variation of the characteristics $P(V)$ of PV module on June 21 for the three positions normal (PN), fixed (PF) and horizontal (PH)

4.3 Case 3: September 21

For September 21 the angle height is 55° at 13h. The corresponding slope of the panel is 35° and the azimuth is 2.5° as shown in the figure (11).

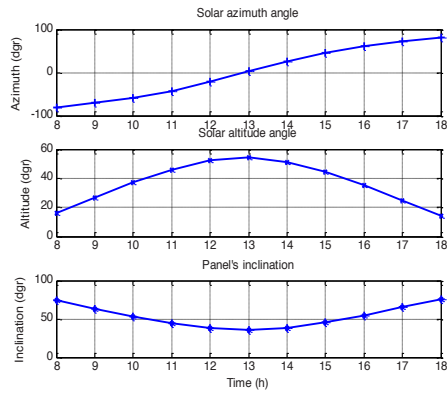


Fig.11: Variation of azimuth (a), altitude (h) and inclination (β) on September 21

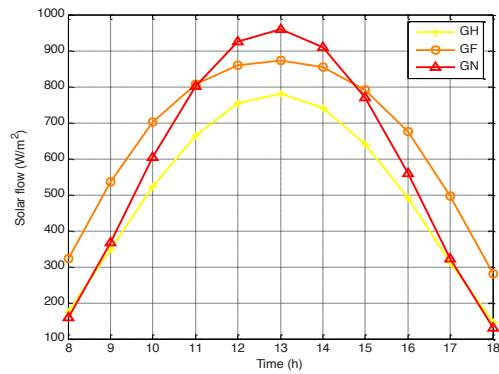


Fig.12: Variation of solar flux for perpendicular plan (GN), fixed plan (GF) and horizontal plan (GH) on September 21

The solar flux reaches $960 \text{ (W/m}^2\text{)}$ in September on a perpendicular surface (Fig.12).

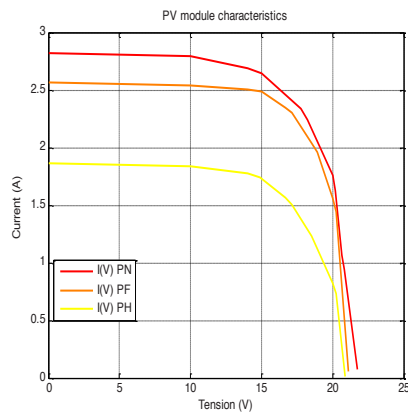


Fig.13: Variation of the characteristics $I(V)$ of PV module On September 21 for the three positions normal (PN), fixed (PF) and horizontal (PH)

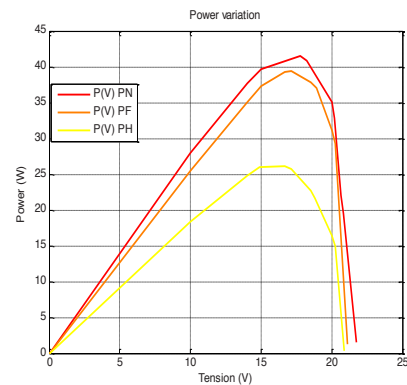


Fig.14: Variation of the characteristics $P(V)$ of PV module On September 21 for the three positions normal (PN), fixed (PF) and horizontal (PH)

The figures (13, 14) show the variations of characteristics for the three selected positions of the panel and the direct influence of solar flux on the collection of the current and the extracted power

4.4 Case 4: December 21

This day correspond the winter season. The solar altitude angle reaches 30° at 13h the corresponding slope of the panel is of 60°

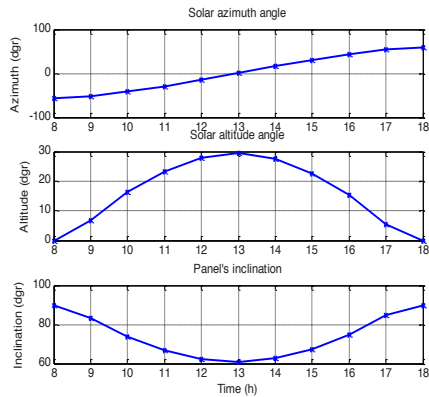


Fig.15: Variation of azimuth (a), altitude (h) and inclination (β) on December 21

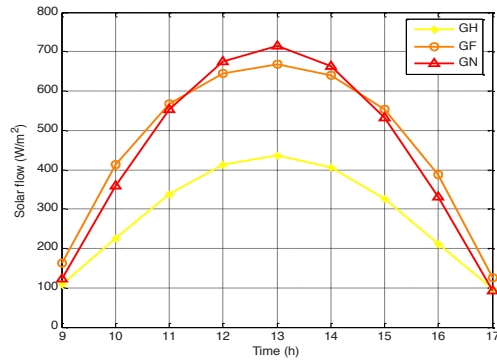


Fig.16: Variation of solar flux for perpendicular plan (GN), fixed plan (GF) and horizontal plan (GH) on December 21

The solar flux drops considerably in December, it reaches on a perpendicular surface $714 \text{ (W/m}^2\text{)}$ (fig.16).

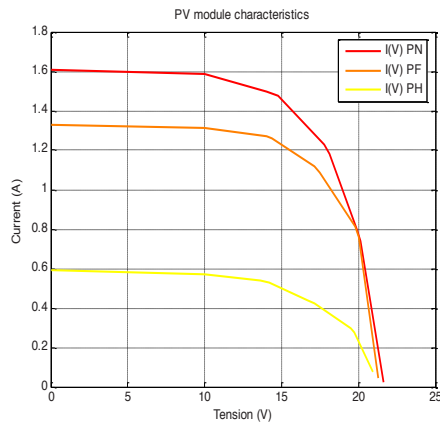


Fig.17: Variation of the characteristics $I(V)$ of PV module On December 21 for the three positions normal (PN), fixed (PF) and horizontal (PH)

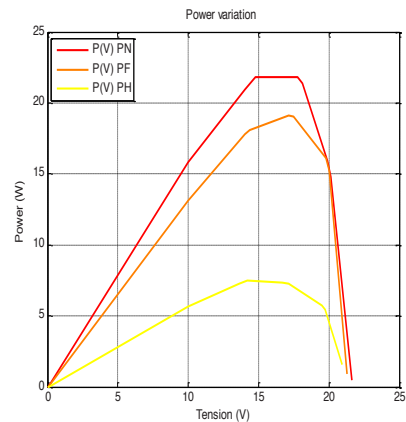


Fig.18: Variation of the characteristics $P(V)$ of PV module on December 21 for the three positions normal (PN), fixed (PF) and horizontal (PH)

Among the three positions of the panel studied for December, the position horizontal plane is the last favourable.

Conclusion

The study presented shows the influence of the variation of the solar angles (azimuth, altitude) and inclination on the solar flux collected by the panel surface for various positions, as well as the effect of the irradiation to give the maximum of the power. The radiation of March 21st, shows us that the total solar flux received on a perpendicular level (figure 4) reached $960 \text{ (W/m}^2\text{)}$, the PV module can deliver a maximum power of 42 W (figure 6) in this position. Solar flux is of $878 \text{ (W/m}^2\text{)}$ on a level inclined with 37 degrees, the corresponding extracted power is of 40 W . For a horizontal plane solar flux reaches $768 \text{ (W/m}^2\text{)}$, the PV module can deliver a power of 29 W .

The variation of the solar radiation on June 21st reaches 1,044 (W/m²) on a perpendicular level (figure 8), it is about 943 (W/m²) on a level inclined with 18 degrees and it approaches 960 (W/m²) on a horizontal level. The figure 10 shows us the variation of power according to the tension corresponding to June 21st, it reaches 48.35 W for the perpendicular position, 43.6 W for the fixed tilted position and 41.71 W for the horizontal position. We note that the extracted power is maximum for the perpendicular position.

The curves of illumination of September 21st, shows us a fall of the total radiation, it is about 960 (W/m²) on a normal level is (figure 12), it is 873 (W/m²) on an inclined fixed plan with 35° and it is close to 780 (W/m²) for an horizontal plan. Figure 14 shows us the variation of power according to the tension, it reaches 41.45 W for a PV module in perpendicular position, 39.41 W for a fixed tilted position and 26.09 W for an horizontal position. We note that the power is maximum for the normal position, whereas it drops for the horizontal position plan.

The various components of the solar radiation fall considerably during December 21st, it is the winter, the total radiation on a perpendicular level is around 714 (W/m²) figure 16. On a fixed plan it is close to 668 (W/m²) and it is about 437 (W/m²) on a horizontal level. Figure 18 shows us the variation of the power according to the tension, it reaches 21.82 W for the perpendicular position, 19.10 W for the fixed tilted position and 7.51 W for the horizontal position. We note that the power which can be extracted by a PV module drops considerably in December, as it is the case for the solar radiation. The power for the perpendicular position remains relatively high compared to the positions tilted fixed and horizontal.

The photovoltaic systems require a follow-up of the trajectory of the sun to optimize their power output. This follow-up must be done by knowing the solar angles (position of the sun) along the day to apply the orientation and the inclination appropriate at each hour of the day at each season and each geographical place.

The nonlinear characteristic of the photovoltaic systems encourages many researchers to synthesize an adaptive intelligent controller to ensure a better output and to introduce a system of storage to ensure a stable distribution of energy for various loads.

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